National Bureau of Standards

TECHNICAL NEWS BULLETIN

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Microwave Measurement Standards

As part of a broad program for the establishment of national standards and calibration services for all electrical quantities at radio frequencies, microwave measurement standards are being intensively developed at the National Bureau of Standards in the range from 300 to 100,000 megacycles and above. This work, under the direction of Dr. Harold Lyons of the Bureau's Central Radio Propagation Laboratory, has resulted not only in extremely precise and accurate standards of frequency, power, attenuation, and other quantities, but has also made possible precision measurements in a whole new field of microwave spectroscopy formerly inaccessible to investigation because of the limitations of infrared and optical equipment. Of basic importance in the microwave program has been the development and continued improvement of a primary standard of frequency accurate to 1 part in 100 million. This standard, based on a quartz-crystal clock and a frequency multiplying system governed by the time observations of the U. S. Naval Observatory, is now being used by the Bureau to provide a regular service to Government and industry consisting of frequency measurements and calibrations of frequency meters and voltage sources.

As a result of research carried on under the pressure of World War II, a vast new spectrum of radio frequencies above 300 megacycles is now available for application to radar, navigation systems, storm and weather reporting, relays for FM and television broadcasting, blind bombing, guided missiles, and many other uses, both peacetime and military. The fundamental requirement for opening up and fully exploiting this new microwave region, however, is the development of national standards and measurement methods for frequencies up to 100,000 megacycles or more. Such standards are necessary tools for the design, development, and production engineering of practical electronic equipment, and for basic research, as in nuclear physics. Many of the new techniques in atomic-energy work, in particular some of the recent billion-volt nuclear particle accelerators, depend upon accurate microwave measurement methods and equipment. Microwave standards are also important in the development and proper use of a number of industrial and medical applications of radio and electronics, such as dielectric heating for case-hardening of metals, rubber curing, plastic molding, food processing, textile fabrication, and radio therapy.

The comprehensive program on microwave measurements began at the Bureau in 1944, when the United States Joint Chiefs of Staff requested the development of a microwave standard of frequency. With the assistance of the Massachusetts Institute of Technology Radiation Laboratory, a preliminary standard was developed in 1945 and placed in service for instrument calibration. As the result of continued research in this field at the Bureau, it is now the most complete and accurate primary frequency standard in the world, having an accuracy of 1 part in 100 million and continuous coverage through the range from 300 to over 40,000 megacycles. Extension of the range to the millimeter bands above 30,000 megacycles, which is now being undertaken, is important for work on microwave spectroscopy, microwave optics, and applications requiring

sharp microwave beams of high resolution, such as short-range target-seeking equipment for rockets and guided missiles.

The frequency source for this equipment is a quartz-crystal unit with a series-resonance frequency of approximately 100 kilocycles per second. The national primary frequency standard consists of nine such oscillators, which are automatically compared with each other and with corrected U. S. Naval Observatory time. The best oscillators are constant to one part in a billion for short-time intervals and drift less than one part in a hundred million per month.

The 100-kilocycle output from the primary standard is first multiplied to 7,500 kilocycles and then added in a converter to the output of one of three precision variable oscillators to give an output that is variable from 9.5 to 10.5 megacycles. The output of the converter is passed through five consecutive frequency multipliers with outputs available in the vicinity of 30, 90, 270, 810, and 2,400 megacycles. Each of these stages has a tuning range of about 10 percent so as to accommodate only the range of variable frequency, making it impossible to tune to any except the proper harmonic. The output from any of the five multiplier stages can be impressed across a nonlinear element, such as a crystal rectifier, which will generate higher-order harmonics.

When continuous frequency coverage is obtained through use of a precision oscillator, the frequency stability of any one of these harmonics is about 95 percent, dependent upon the primary standard, and only 5 percent dependent upon the oscillator. A suitable electronic circuit measures the instantaneous frequency of the oscillators to within 1 cycle, thus giving an over-all accuracy for continuous coverage of 1 part in 10 million.

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Charles Sawyer, *Secretary*
National Bureau of Standards
E. U. Condon, *Director*

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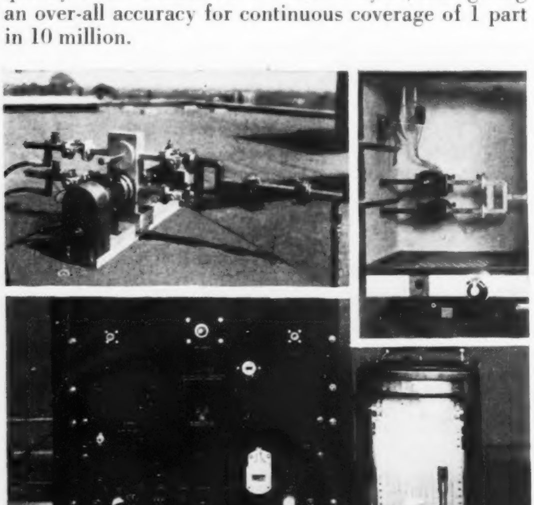
Contents

At times a calibration is needed at several points within a range of frequencies rather than at a particular frequency. To obtain such a series of precisely known frequencies easily, spot-frequency generating equipment is used in which the frequency is at all times dependent directly upon the primary standard. Here the precision oscillators are replaced by a system of multipliers and converters, known as the decade generator, which gives an output adjustable in 100-kilocycle steps from 2.0 to 3.0 megacycles. This is accomplished by adding to a 2.0-megacycle frequency the output of any one of a series of frequency multipliers, which provide outputs every 100 kilocycles from 100 to 1,000 kilocycles. This frequency is then added to the 7.5-megacycle output and passed through the frequency multipliers as before. Any one of the outputs is now adjustable over an approximately 10-percent range at intervals of 1 percent. As these frequencies are derived directly from the primary standard, they are known to within 1 part in 100 million. Although the output from the microwave frequency standard is tunable over a relatively narrow frequency range, continuous frequency coverage can be obtained through



This refractometer makes a continuous record of changes in dielectric constant, or index of refraction, of the atmosphere or other gases at microwave frequencies. Components for measurements at 3,000, 9,000, and 24,000 megacycles are shown in the foreground. Left insert: A modified arrangement that measures the dielectric constant of chemicals while reacting. Right insert: Another arrangement mounted in a temperature-controlled oven for measuring the dipole moment, or electric asymmetry, of gas molecules.

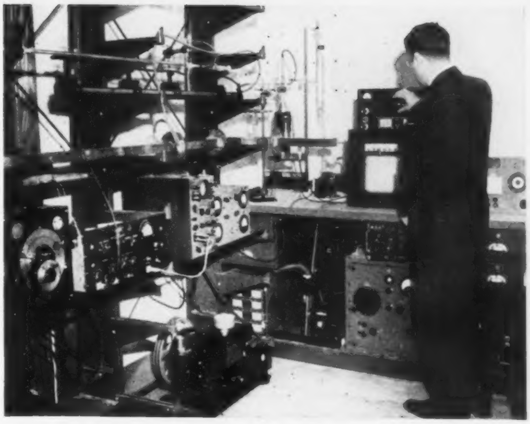
the overlapping of harmonics. With the 10-percent bandwidth being used, harmonics above the tenth overlap.

The output of any one stage may be used up to the thirtieth harmonic with power sufficient for frequency calibration purposes. To generate these high-order harmonics, the output from any one of the five frequency multiplier stages is impressed across a crystal diode mounted in a coaxial line or a section of wave guide.

To calibrate an unknown signal or frequency meter at frequencies below 2,700 megacycles, a superheterodyne receiver is used with a panoramic adapter. For the high frequencies, a spectrum analyzer, consisting essentially of a superheterodyne receiver with a frequency-modulated local oscillator, is employed. Although the standard microwave frequency is known to 1 part in 100 million, it is practically impossible to certify a frequency meter to this accuracy. Many factors enter into the exact determination of the resonance frequency, limiting the accuracy of the usual meter to about 1 part in 100 thousand or less.

In addition to work on the microwave frequency standard, the problems involved in the development of microwave standards of power, attenuation, impedance, field intensity, and noise and of dielectric and magnetic measurements are being strenuously attacked at the Bureau. The production of new insulating and dielectric materials for microwave radio equipment requires standard samples and dielectric measuring equipment, particularly at the upper ranges, where power losses in present materials are serious. The development of microwave optics, allowing the use of lenses, prisms, and other optical elements in radio, will be advanced when suitable materials are found. Radomes for radar sets also urgently require improved materials. Techniques have therefore been developed and equipment constructed for dielectric measurements in the 1,000-, 3,000-, 9,000-, and 24,000-megacycle ranges. Both resonant-cavity and impedance methods are used. In the first method the dielectric sample is placed in a resonant cavity and the change in frequency and Q measured, whereas in the second the impedance of a section of line containing the sample is determined. Other procedures are also under investigation. For example, a microwave refractometer has been completed that continuously records the index of refraction or dielectric properties of atmospheric air. This new instrument will aid materially in FM, television, and radar propagation studies, since the index of refraction along the propagation path determines the course of a radio wave and hence its range.

The problem of a primary standard of attenuation capable of measurements at all microwave frequencies has been very satisfactorily solved with the design of a new waveguide-below-cutoff primary standard of higher accuracy than has previously been attained. This standard is needed for signal-generator, power, and voltage calibrations of transmitters, receivers, and other equipment so that, for example, the range of communication and radar transmitters can be kept up to the proper operating levels.



The Bureau's microwave spectrometer will extend the precision and frequency coverage of presently available absorption lines used as frequency standards. Sensitive detection of spectral lines is aided by an absorption cell (the horizontal rectangular pipe) in which the Stark effect is used to modulate a wave traversing the cell.

Attenuators are calibrated to read power ratios directly in decibels and are used to control the power level of microwave signals in any system, such as a receiver, signal generator, or power meter. Because of the tremendous range of the microwave spectrum over which attenuators must be calibrated, the design of a series of standard microwave attenuators to cover the entire spectrum and the use of the direct substitution method of calibration are not practicable. A technique for use in calibration at any frequency was therefore worked out at the Bureau by development of the heterodyne or intermediate-frequency substitution method. This method permits the comparison of an unknown attenuator, operating at an arbitrary frequency, with the standard attenuator operating in the intermediate-frequency channel of a superheterodyne detecting and measuring receiver. Thus, one standard attenuator, operating at a convenient frequency, may be used to calibrate attenuators over the entire microwave spectrum.

Essentially, the heterodyne method operates as follows: A radio-frequency generator feeds power through an unknown attenuator into a linear frequency converter, which converts the microwave frequency into the intermediate frequency. The converter feeds through an intermediate-frequency standard attenuator into an amplifier, followed by a detector and meter. The unknown attenuator then is removed, and the standard attenuator adjusted to give the same meter reading. The attenuation of the unknown is then equal to the increase of attenuation of the standard.

This method assumes that the frequency converter is linear; that is, that the intermediate-frequency power from the converter is proportional to the input microwave power. For small enough input power this is true for a crystal converter, and the operating conditions for a prescribed degree of linearity may be determined experimentally.

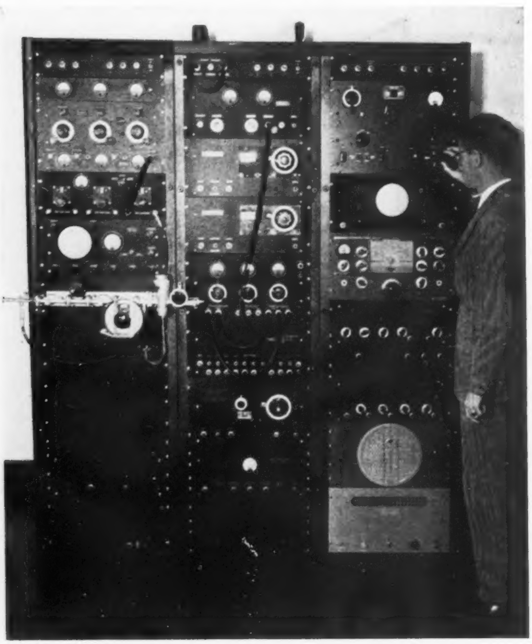
The theoretical attenuation constant of this standard attenuator, which can be calculated by electromagnetic theory, has been checked experimentally to better than 0.01 decibel. Linearity of the attenuator is secured by highly symmetric construction and the use of mode filters. A new, improved version of the attenuator that uses an electroformed, rectangular waveguide will continuously cover a range up to 100 decibels and will be temperature-insensitive and free from mechanical wear. Mechanical accuracy of better than 0.001 decibel is obtained, and electrical accuracy approaching this figure is expected through the use of the rectangular waveguide and improved measurement methods.

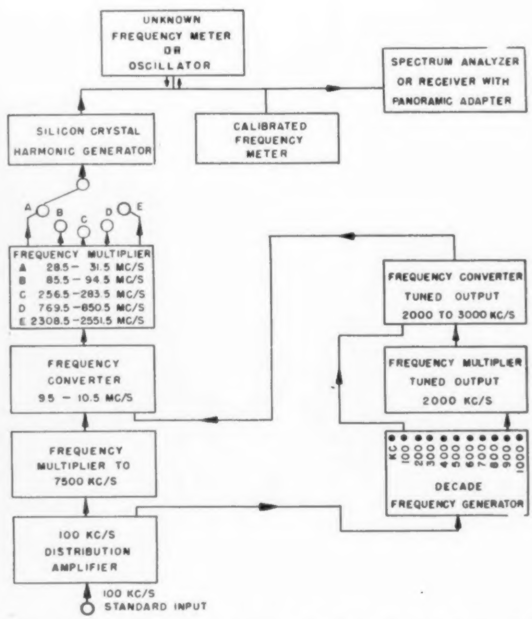
Accurate power meters are needed for dosage measurement in radiation therapy as well as in the measurement of the intensity of spectral lines and the power of transmitters. Development and construction of the most precise microwave power-measuring console in existence has been largely completed; theoretical and experimental work has also been carried out on bolometer mount losses, which for the first time threw light on the accuracy of bolometer power meters as primary, absolute standards. An investigation of thermal noise sources as power standards has begun and ultrasensitive calorimeters are being planned for precision power measurements of high absolute accuracy.

Research, having as its object the extension of microwave standards for all electrical quantities to higher frequencies, is continuing at the Bureau. In the frequency standard, higher powers than ever before have been generated at the upper end of the range by means of a new lighthouse tube frequency multiplier recently devised at the Bureau. By harmonic generation, it should be possible, with the development of suitable crystal rectifier mounts, to obtain useful outputs to 100,000 megacycles and above. These extremely high frequencies may require the introduction of new frequency-measuring instruments similar to optical apparatus.

Development of invariant primary and secondary frequency standards, by using spectrum lines of gases, is also well under way. Absorption cell techniques and methods have been formulated by the use of atomic beams in which the resonance frequencies of individual atoms serve as standards for timekeeping and frequency measurements. The extension in frequency range is making possible work on microwave spectroscopy, as well as applications to equipment development by the use of millimeter waves. Such short waves permit the use of sharp microwave beams with small, light antennas.

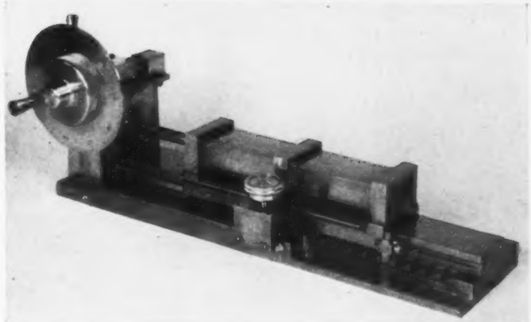
Spectroscopic analysis has hitherto been dependent on infrared, optical, and ultraviolet methods, which for the most part are limited to work on atoms and the simpler molecules. However, a large part of medical and industrial chemistry requires analyses of large, complicated molecules. The recent advances in microwave measurement techniques, opening up the new field of microwave spectroscopy, now provide methods of unprecedented accuracy and resolution for the study





The primary microwave frequency standard (left) multiplies the 100-kilocycle output of one of the Bureau's standard quartz-crystal oscillators to cover a range of 300 to 40,000 megacycles. A diagram of the multiplying system for providing spot frequencies is shown at right. Frequency is now maintained constant to one part in 100 million. However, work in progress should increase still further the precision and stability of the standard by making use of the invariant resonance frequencies of individual atoms or molecules.

A new primary standard of attenuation developed at the Bureau permits accurate calibration of attenuators over the complete microwave spectrum by a heterodyne method. Of the waveguide-below-cutoff type, it controls nd precisely measures changes in power level to one part in 5,000 over a range of 10 billion to 1.



of new atomic and molecular properties. Spectroscopic research, now under way at the Bureau, is also yielding a basically new, primary standard of frequency and time that is invariant with age. Specifically a preliminary model of an atomic clock has been developed by using spectral lines. The atomic-clock method promises to surpass the accuracy of the rotating earth as a timekeeper by one or two orders of magnitude.

In order to apply microwave spectroscopy to standards and measurements work, new wide-range search and precision measurement spectrometers have been designed and are under construction. Work has also begun on the measurement and compilation of spectrum lines as secondary frequency standards. These investigations are being extended below the frequency range of presently available lines and later will be extended far up into the millimeter bands.

The Bureau's research in microwave spectroscopy has resulted not only in an atomic clock and frequency standard, but also in the development of stabilized oscillator-frequency multiplier chains locked to a spectrum line by means of a servo-type electronic circuit. The Bureau's work has also shown that directly controlled oscillators, analogous to low-frequency quartz-crystal oscillators, can be built in which an absorption line replaces the quartz crystal. Such circuits will have extensive application to frequency measurement and control of transmitters for FM and television relays, communications, and radar.

Physical Constants of Leather and Collagen

Expanded Bureau research in the field of leather has added fundamental data on the physical and physicochemical properties of leather and its parent substance, collagen. These constants are largely unknown, even though the art of leather manufacture predates historical records. Published data are lacking on such properties as expansivity, compressibility, dry density, and specific heat. Results of the program, sponsored by the Office of the Quartermaster General, should prove of value to the entire leather industry, whose facilities for research of this nature are limited.

The lack of such data may be attributed directly to the extreme chemical and physical complexity of the system of tanned collagen fibers known as leather. Although many workers are inclined to believe that leather is not a pure substance and is subject to variation because of differences in the hide itself and those introduced by nonuniformity of the tanning process, it is a matter of practical as well as theoretical interest to determine either the values of the physical constants or their orders of magnitude. A knowledge of these constants may permit utilization of leather in applications requiring specific properties possessed by leather but as yet unknown. The effect of tannage and other treatments on their values may yield valuable information concerning the structure of collagen and the mechanism of tanning.

Since leather is a porous material containing as much as 60 percent of void space, most measurements of physical properties of the leather substance present obvious difficulties. One method of solving this problem lies in completely filling the leather with a liquid and ascertaining the properties of the liquid-leather system. This approach was used by Charles E. Weir, of the Bureau's leather laboratory, to obtain data on the cubical expansivity of leather.[1] Using water as the confining liquid, dilatometric measurements of the volume of a water-leather system were made and compared with measurements on a similar system containing water alone.

If a system containing leather in water is heated, it is known that above a well-defined temperature, depending on tannage and other factors, the leather undergoes a dimensional change, commonly called shrinkage. During this process the area decreases drastically, while the thickness increases. The temperature at which this process begins is defined as the shrinkage temperature and is considered a measure of the efficiency of the tanning process—the higher the temperature, the more thorough the tannage. During the dilatometric studies, it became evident that the apparent shrinkage actually represented an increase in real volume. This increase in volume amounted to approximately 1 percent and was irreversible in character, although the purely thermal expansion was found to be nearly completely reversible.

It was also observed that this increase in real volume occurred very slowly at temperatures well below the shrinkage temperatures of the specimens found by regular test methods. This indication that shrinkage was a rate process was substantiated by a rate measurement that indicated that the expansion occurring during shrinkage follows a first-order process.

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[1] For further technical details, see Effect of temperature on the volume of leather and collagen, by Charles E. Weir, J. Research NBS, 41, 279 (1948) RP1924.

Accelerometer Calibrators

Type calibrator	Frequency	Range	Acceleration control
	Cycles/sec	*Gravity*	
Centrifugal	0	0 to 1,000	Continuously variable
Shake table	10 to 115	5 to 100	Continuously variable within limits
Portable pulse	30	0.8 to 19.5	Six steps

The increasing use of accelerometers for motion studies, capable of recording accelerations applied in a few thousandths of a second and with ranges as high as 500 times gravity in extreme cases, has necessitated the development of improved methods for their calibration. Advanced research testing of guided missiles, high-speed aircraft, airplane-crash and landing-impact phenomena, and seat-ejection devices has expanded the demand for accurately calibrated accelerometers in the higher ranges. Following recent investigations in this field for the Bureau of Aeronautics, Department of the Navy, scientists of the Bureau's engineering mechanics laboratory have designed and constructed three types of calibrators that show remarkable correlation in their results, even though they are based on different principles of operation.[2] At the same time, they effectively reduce the limitations encountered with other calibrators for accelerometers. With the new calibrators, means are provided for subjecting light accelerometers, up to ½ pound in weight, to known accelerations over a wide range of acceleration and frequency.

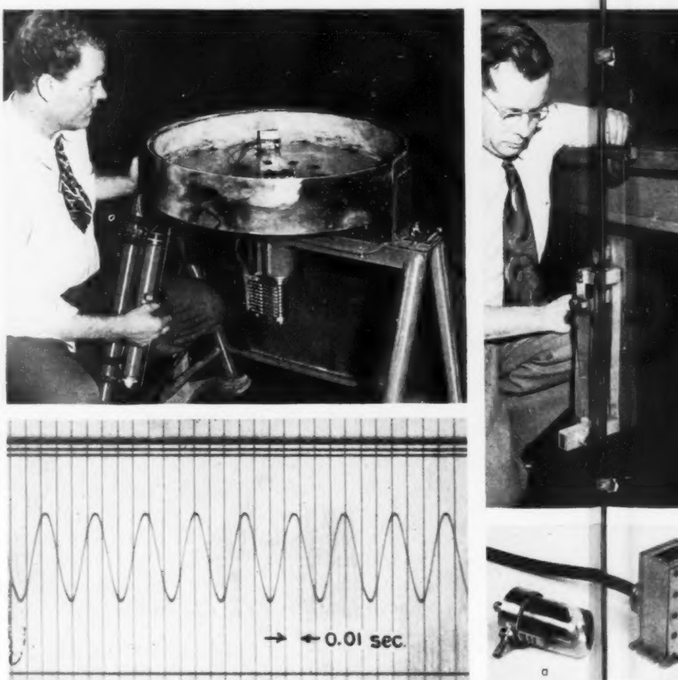
Accelerometers are in general constructed with a base, a seismic mass, an elastic coupling between the mass and base, and a means of measuring the force in the coupling required to accelerate the mass in a manner similar to that experienced by the base. It is important that the natural frequency of the coupling and seismic mass be appreciably greater than that of the phenomena under consideration, because resonant response will otherwise invalidate any indication obtained. It is common practice to use instruments having natural frequencies much higher than those present in the motion to be measured, or to use some means of damping out the natural-frequency response.

A completed accelerometer is generally an instrument so complicated that the linear relationship between base acceleration and output can be predicted only approximately from its basic design. Calibration is therefore necessary to determine the relationship with sufficient accuracy. For such a calibration, accelerations are applied to the instrument in the laboratory at frequencies and temperatures over which it is expected to operate. The output, which may be a voltage, resistance, or other measurable change, will usually be small in magnitude; however, it can be measured with precision by using laboratory equipment.

In some cases, particularly just prior to use in the field, it is necessary to calibrate the accelerometer when it has been attached to its complete amplifying and recording equipment, in order to obtain an "over-all" calibration. For such calibration a portable calibrator is desirable.

The first type affords an ideal means of subjecting accelerometers to a steady acceleration. The second type is very useful for subjecting accelerometers to sinusoidally varying accelerations of known frequency and amplitude. These two calibrators are primarily laboratory instruments. The third type provides a convenient and readily portable means of calibrating complete accelerometers and their associated equipment in the field.

In the centrifugal calibrator, a direct-current motor drives a horizontal table in the form of an aluminum

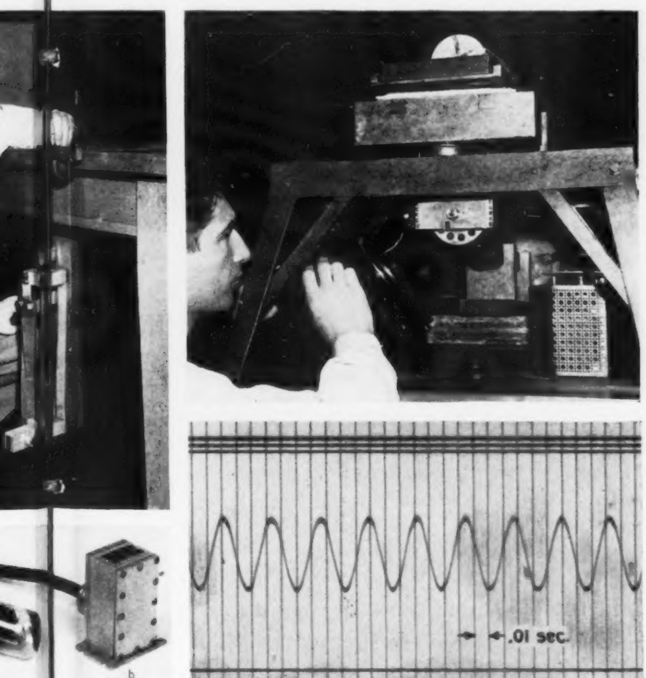


Remarkable correlation has been obtained between calibrations accelero and constructed at the Bureau, even though the calibrators are ed on di trifugal, portable pulse, and sinusoidal shaking-table types. Th even re left) and a commercial instrument (lower right) (*a* and *b*, respectively, ce cate that the motion of the table is smooth and fr

² For further technical details, see Calibration of accelerometers, by Samuel Levy, Albert E. McPherson, and Edward V. Hobbs, J. Research NBS 41, 359 (1948) RP1930.

alloy disk 22 inches in diameter and ½-inch thick, at speeds up to 2,000 revolutions per minute. The instrument to be calibrated is bolted to the disk near its outer edge and the necessary electrical connections for reading the instrument are made to a set of binding posts mounted on the disk. Up to nine electrical connections can be brought out by means of copper-graphite brushes on copper slip rings. The weight of the instrument being calibrated is balanced by a similar weight placed diametrically opposite on the table. This, however, need not be a precision balancing operation, because the whole calibrator is shock-mounted to have a horizontal natural frequency of about 5 cycles per second, permitting the table to find its own center at practical calibrating speeds. The acceleration on the test instrument is calculated from the rotational speed of the table and the radius from the center of the table to the center of mass of the seismic element of the accelerometer.

When utilizing the shake-table calibrator, the accelerometer under test is attached to a carriage that carries an unbalanced wheel and is supported by parallel flexure plates from a heavy base. The unbalanced wheel is driven by a very light thread belt, which is in turn driven by a direct-current electric motor equipped with speed control. In operation the unbalanced wheel is driven at a frequency well above the natural frequency of the suspended carriage, so that



ation[s] [of] accelerometers by means of three types of calibrators designed
s are [bas]ed on different principles of operation: (top, left to right) Cen-
es. Th[e] even records from the NBS vacuum-tube accelerometer (lower
, resp[ecti]vely, center), when attached to a shaking-table calibrator, indi-
e is sm[oot]h and free from objectionable "hash."

the displacement will be more or less constant with varying frequency. The entire calibrator is shock-mounted to isolate it from building vibration, whereas the driving motor, carefully selected to be vibration-free, is entirely supported by sponge rubber.

In order to cover the full range of frequency it is necessary to employ several sets of flexure plates. Thicker plates are used at the higher frequencies to eliminate secondary resonant responses. The unbalance of the wheel, which controls the amplitude of the carriage, can be changed by varying the weight of the unbalance or by changing the vector sum of the forces produced by two weights placed in holes around the periphery of the wheel.

The maximum acceleration is computed from the rotational speed of the wheel and the displacement of the carriage. This displacement is measured with a reticulated telescope focused on an illuminated wire (0.001 inch in diameter) mounted on the carriage. To obtain maximum contrast for viewing the wire, it has been mounted across a small opening in a black paper box. The accuracy of displacement readings can thus be determined to about 0.001 inch.

The pulse calibrator consists essentially of a three-mass system suspended from any convenient support by means of a wire hanger. Before it can be used to calibrate accelerometers, the calibrator itself must be calibrated. In order to do this, the third mass, (M_3), is pressed toward the first, (M_1), and held by a pawl in a sprung position at one of six steps on a rachet. When the pawl is drawn to release mass 3, the second mass, (M_2), experiences a pulse of acceleration having two frequency components, 12 and 30 cycles per second. The second peak of this acceleration is taken as the calibrating pulse. This peak, which rises gradually from zero, exhibits the characteristics of acceleration pulses frequently encountered in objects under test. The choice of springs and masses has been made so that the effect of the weight of the accelerometer under test on the *g* value of the pulses is practically zero.

The magnitude of the acceleration "pulse", corresponding to release from a given ratchet point, was determined from the acceleration of gravity, by using an accelerometer as an intermediate standard. An NBS vacuum tube accelerometer [3] was first mounted on the calibrator and a record of acceleration for release from a given ratchet point was taken. Then the same vacuum tube was attached to a heavy mass and a record of acceleration for a 1–g change was obtained by suddenly releasing the mass. The ratio of the amplitude of the second peak of the calibrator record to the amplitude of the 1–g record was taken as the *g* value for the given ratchet point.

The operation of the pulse calibrator consists of suspending the calibrator with test accelerometer attached to mass 2, cocking to the desired ratchet point, and releasing the mass by drawing the pawl. The instrument, which weighs about 30 pounds, can be set up in the field, permitting "spot" calibrations of complete acceleration-measuring systems.

[3] See Vacuum-tube acceleration pick-up, by W. Ramberg, J. Research NBS **37**, 391 (1946) RP1754.

The performance of the different calibrators was compared by calibrating two different accelerometers on each of the three calibrators. One of the accelerometers was of the NBS vacuum-tube type. It was undamped and had a natural frequency of about 800 cycles per second. The other was a commercially available accelerometer employing strain-sensitive wire as a transducer. This accelerometer was damped to 0.7 critical and had a natural frequency of about 350 cycles per second. Calibrations of these accelerometers on the three calibrators were found to differ by less than 3 percent. Similar results were subsequently obtained in calibrations of other accelerometers.

The good agreement between calibrations obtained from the different calibrators was taken as an indication that extraneous noise and "hash", which had made it difficult to obtain reliable calibrations in the past, were not prominent in these calibrators.

Weather Resistance of Porcelain Enamels

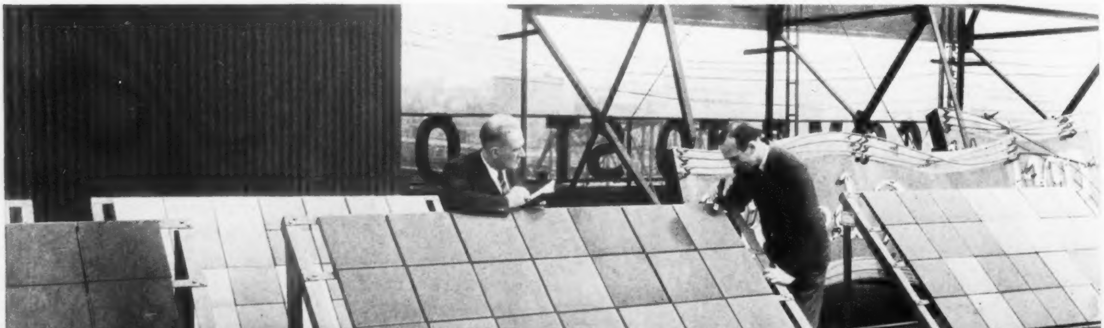
During the past few years the increased use of porcelain-enameled steel as an architectural material has accentuated the need for adequate data on the weathering resistance of various types of porcelain enamels. In 1939 the National Bureau of Standards began a long-range, systematic study of the weather resistance of porcelain enamels. Specimens including both acid-resistant and non-acid-resistant types were supplied by 16 cooperating manufacturers and exposed to four different climatic conditions, namely, temperate residential, temperate industrial, temperate "salt air," and semitropical residential. Five duplicate sets of specimens were prepared. One of these was placed in storage and the other four installed at selected exposure sites in Washington, D. C.; St. Louis, Mo.; Atlantic City, N. J.; and Lakeland, Fla. Two inspections of the panels, the first at the end of 1 year and the second at the end of 7 years, have now been completed.

That porcelain enamels, when properly selected, have excellent durability against the destructive action of weathering is widely recognized. For example, there are reliable reports of porcelain-enameled street and advertising signs that have been exposed for as long as 25 years without apparent deterioration of the enamel. However, all enamels are not equally resistant to weathering.

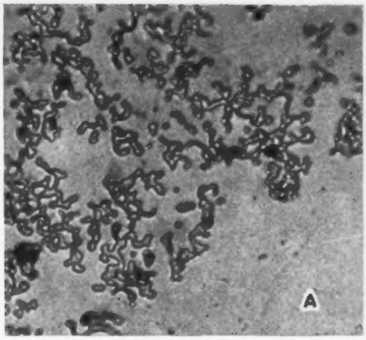
The present study was undertaken to determine which types of enamel are the most resistant to weathering under various typical climatic conditions and to develop, if possible, an accelerated test, by means of which the most durable types can be selected in the laboratory. Mass production of prefabricated porcelain-enameled steel houses has focused new interest on both phases of this investigation.

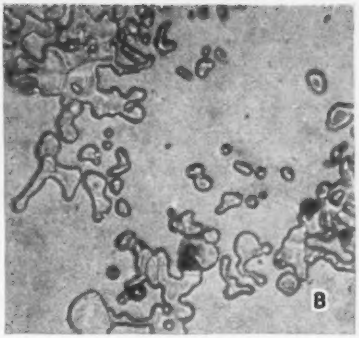
A complete inspection of the panels at the four locations was made at the end of 1 year, and the results were reported at that time. Because of war conditions, the second inspection was not completed until 1947,[4]

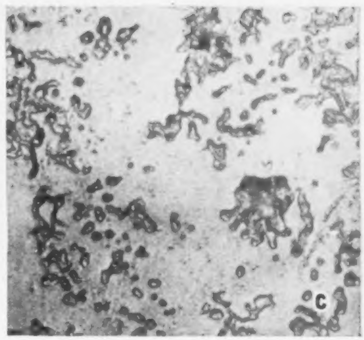
[4] For further technical details, see Weather resistance of porcelain enamels exposed for seven years, by W. N. Harrison and D. G. Moore, J. Research NBS 42, (January 1949) RP1949; also J. Research NBS 28, 735 (1942) RP1476.



The weather resistance of various types of porcelain enamels designed for outdoor use is being studied through the exposure of specimen panels at selected sites in Washington, D. C., St. Louis, Mo., Atlantic City, N. J., and Lakeland, Fla. These locations were chosen to represent four different climatic conditions, namely, temperate residential, temperate industrial, temperate "salt air," and semitropical residential. Two inspections of the panels have been made, after 1 year and after 7 years.







Photomicrographs (X600) of a red, semi-mat porcelain enamel of good acid resistance reveal no appreciable change in microstructure from weathering during a 7-year period: (A) Unexposed; (B) exposed for 1 year in Washington, D. C.; (C) same as B, but exposed for 7 years. The particles appearing at the surface are undissolved material added to the enamel to give a mat finish.

when the panels had been exposed for 7 years. From the standpoint of protection of the metal against corrosion, all of the enamels were satisfactory throughout the entire period. Practically all the panels showed some measurable change in surface properties, but in most cases these changes were not noticeable unless direct comparisons were made between the test specimen and the storage specimen of like composition.

The specimen panels, 1 foot square, were fabricated of 16-gage iron with 1-inch flanged edges. The flange on the lower side had a $\frac{1}{2}$-inch outward extension parallel to the face of the panel. Two clips, made of 1-inch strip iron, were welded to the top flange so as to extend downward. The clips and the lower flange extensions were fitted into galvanized-iron channels, which in turn were firmly attached to the supporting racks. The crevices between the specimens were not calked, in order to facilitate removal of the panels during periods of inspection and subsequent replacement. Seven racks were provided for each of the four locations, and the racks were constructed to support 28 of the panels at an angle of 45° to the horizontal.

Before the panels were exposed, several characteristic properties were measured and recorded. They were first washed with a warm 1-percent solution of trisodium phosphate, thoroughly rinsed in hot tap water, and dried in air. Specular-gloss measurements, involving the percentage of light incident at 45° that is regularly reflected (as by a mirror), were made with the Hunter Multipurpose Reflectometer at two fixed points near the center of the surface to be exposed. Reflectance values with blue, green, and amber filters were obtained with the same instrument at the two lower corners of each specimen as a means of obtaining a permanent record of the initial color. The panels were also examined visually for surface defects, and a record was made for future reference. At each location, panels were exposed in duplicate; this arrangement accounted for eight of the nine panels constituting each set. The same initial measurements were also made on the ninth panel, which was then stored indoors for subsequent comparison with exposed panels.

In contrast to the results of the first-year inspection, which showed weathering effects to be most prominent at St. Louis and Washington, the 7-year data indicate that the conditions at Atlantic City were most severe on the acid-resistant enamels, whereas Lakeland conditions were most severe on the non-acid-resistant compositions. The data from the St. Louis panels at 7 years were not consistent with the earlier observations because of a heavy, adherent, tar-like deposit originating from heavy smoke concentration in the test area, which was near a railway terminal. The resulting film was protective, but would not normally have been permitted to accumulate for a 6-year period.

Good correlation existed between the weather resistance, as measured by the average percentage of the initial gloss retained, and the acid resistance, as determined by the standard Porcelain Enamel Institute test. The test separates specimens into classes according to visual effects noted after 15 minutes' exposure to a 10-percent solution of citric acid at 80° F.

On the basis of the 7-year data obtained by the Bureau, the acid resistance of the enamel surface appears to be the best available accelerated test for predicting weather resistance.

The average percentage of initial gloss that is retained by the porcelain enamels is taken as a measure of their weather resistance. Gloss measurements are made by means of the Hunter Multipurpose Reflectometer.

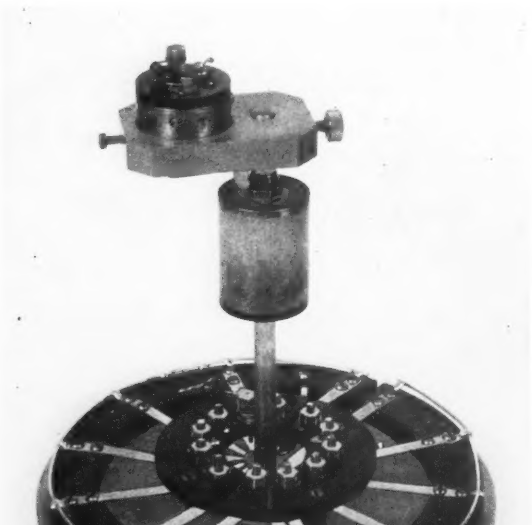
Automatic Calibrator for Producing Equi-Step Potentials

In precision measurements of rapidly changing voltages, it is often desirable to calibrate the recording instrument as soon as possible after the record has been completed. For example, in making a continuous record of the electrical potential developed by a lightning stroke, it may be essential to calibrate the recording instrument before the arrival of the thunder, since the shock of the air-wave might change the calibration. Similar considerations led H. L. Curtis, of the National Bureau of Standards, and H. S. Roberts, of the Geophysical Laboratory, to devise a method for calibrating cathode-ray oscillographs used to measure the ballistic phenomena of cannons because the best results were obtained when the recording instruments were within 100 feet of the gun.[5]

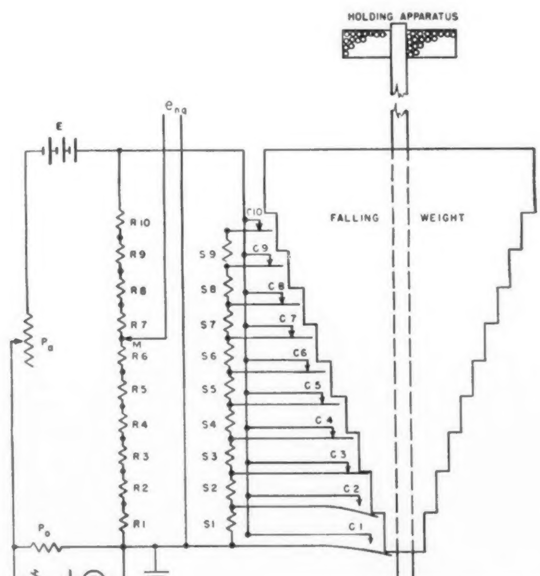
The instruments for measuring the pressure of the powder gases, their temperature, and the velocity and acceleration of recoil were so designed that each produced an electrical potential which was related to the magnitude of the phenomenon to be measured. This potential was applied to the plates of a cathode-ray oscillograph, and the deflection was recorded on a rapidly moving photographic film. Because the deflection was not always proportional to the applied potential, a calibration consisted in recording the deflections produced by several known voltages that were applied in rapid succession to the oscillograph plates, thus producing a staircase record of potentials.

The potential steps were obtained by having a falling weight open contacts in succession so as to introduce resistance into an electrical circuit. The principle involved in the calibrator is the increase by a known amount of the current in a standard resistance, so that the potential between the terminals of the resistance is likewise increased by a definite amount. The calibrator and the measuring instrument are connected in series. While the instrument is making its record, the calibrator is at zero setting, so that the record is not influenced by the calibrator. The height of the falling weight is adjusted to open the calibrator switches after the signals of the measuring instrument have become zero. Thus the "staircase" calibrating potentials are impressed on

[5] For further technical details, see An instrument for the rapid production of a decimal series of potentials and its application to ballistic measurements, by Howard S. Roberts and Harvey L. Curtis, J. Research NBS **41**, 45 (1948) RP1902.



The automatic oscillograph calibrator depends upon a falling weight (cylinder, top center) whose height is adjusted to open the calibrator switches (thin strips radiating to outside ring) after the signals of the measuring instrument have become zero.



As the contacts of the automatic calibrator are opened by the falling weight, a "staircase" of calibrating potentials is impressed on the oscillograph plates, and the deflections are registered on a photographic film within a few milliseconds.

the same oscillograph plates, and the deflections are registered on the photographic film within a few milliseconds after the record is completed.

The unit was designed, constructed, and applied to ballistic studies by the Bureau's interior ballistics laboratory. Although this instrument was developed to provide a decimal staircase, the maximum of which is adjustable from 10 to 100 mv, the principle may be applied to calibrators that will give any desired number of potential steps.

NBS Publications

Periodicals [6]

Journal of Research of the National Bureau of Standards, volume **41**, number 5, November 1948. (RP1930 to RP1937 inclusive.)

Journal of Research of the National Bureau of Standards, volume 40, Title page, corrections, and contents, January to June 1948. (RP1850 to RP1895, inclusive). 5 cents.

Technical News Bulletin, volume **32**, number 11, November 1948. 10 cents.

CRPL–D50. Basic Radio Propagation Predictions for January 1949. Three months in advance. Issued October 1948. 10 cents.

Nonperiodical

Research Papers [6, 7]

RP1922. Color perceptions of deuteranopic and protanopic observers. Deane B. Judd. 15 cents.

RP1923. Electrode function (pH response) of the soda-silica glasses. Gerald F. Rynders, Oscar H. Grauer, and Donald Hubbard. 10 cents.

RP1924. Effect of temperature on the volume of leather and collagen. Charles E. Weir. 10 cents.

RP1925. Image shifts caused by rotating a constant-deviation prism in divergent light. James B. Saunders. 10 cents.

RP1926. Thimble-chamber calibration on soft X-rays. Frank H. Day. 10 cents.

RP1927. Sources of error in and calibration of the *f*-number of photographic lenses. Francis E. Washer. 10 cents.

RP1928. Mass spectrometric investigation of the thermal decomposition of polymers. Leo A. Wall. 10 cents.

RP1929. Purification, purity, and freezing points of 30 hydrocarbons of the API-Standard and API–NBS series. Anton J. Streiff, Janice C. Zimmerman, Laurel F. Soule, Marie T. Butt, Vincent A. Sedlak, Charles B. Willingham, and Frederick D. Rossini. 20 cents.

Circulars [6]

C460. Publications of the National Bureau of Standards. 1901 to June 30, 1947. 75 cents.

C470. Precision resistors and their measurement. James L. Thomas. 20 cents.

C473. Measurement of radioactive isotopes. Leon F. Curtiss 5 cents.

Commercial Standards [6]

CS77–48. Enameled cast-iron plumbing fixtures. (Second edition. Supersedes CS77–40). 10 cents.

CS150–48. Hot-rolled rail steel bars (Produced from tee-section rails). 10 cents.

Letter Circulars [8]

LC922. Bibliography of some recent research in the field of high polymers. (Supersedes LC871 and Supplement.)

LC923. Acoustics: Publications by members of the staff of the National Bureau of Standards. (Supersedes LC778).

Articles by Bureau Staff Members in Outside Publications [9]

Some properties of materials used for jewel instrument bearings. Herbert Insley, H. F. McMurdie, W. H. Parsons, and B. L. Steierman. American Mineralogist (c/o Dr. Earl Ingerson, U. S. Geological Survey, Washington 25, D. C.) **32, 1** (1947).

Determination of iron in glass sand. J. J. Diamond. J. Am. Ceramic Soc. (2525 North High Street, Columbus 2, Ohio) **31,** 243 (1948).

Effect of support on the performance of vane anemometers. G. B. Schubauer and G. H. Adams. Heating and Ventilating (148 Lafayette Street, New York 13, N. Y.) **45,** No. 4, 78 (1948).

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[6] Send orders for publications under this heading only to the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Annual subscription rates: Journal of Research, $4.50 (foreign $5.50); Technical News Bulletin, $1.00 (foreign $1.35); Basic Radio Propagation Predictions, $1.00 (foreign $1.25). Single copy prices of publications are indicated in the lists.

[7] Reprints from October Journal of Research.

[8] Letter Circulars are prepared to answer specific inquiries addressed to the National Bureau of Standards, and are sent only on request to persons having a definite need for the information. The Bureau cannot undertake to supply lists or complete sets of Letter Circulars or send copies automatically as issued.

[9] These publications are not available from the Government. Requests should be sent direct to the publishers.

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